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TECHNICAL REPORT ARCCB-TR-92033

FAILURE ANALYSES OF M3A1 BASEPLATE FOR 81-MM MORTAR 252

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JULY 1992

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13. ABSTRACT *(Maximum 200 words)*

A metallurgical evaluation of a failed 81-mm M3A1 mortar baseplate was undertaken. The evaluation consisted of the following analyses: visual, dye penetrant, scanning electron microscopy/electron dispersive spectroscopy, chemical, metallographic, and mechanical property. The investigation concluded that there was no evidence of a defective material condition and that the probable mode of failure was a ductile, fast fracture under high load.

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INTRODUCTION

In May 1988, Advanced Engineering Branch of Benet Laboratories was requested by Product Assurance Engineering Division of Watervliet Arsenal to conduct a metallurgical evaluation of an M3A1 baseplate, SN EXP6, which had failed during firing. Figures 1 through 4 show the baseplate. This baseplate was used in an ammunition test at Combat Systems Test Activity, Aberdeen Proving Ground, MD, when the failure occurred. The Weapon Record Data, 2408-4 card, indicated a total of 1997 rounds had been fired. The last "ZYGLO" fluorescent inspection was conducted on 13 August 1987 at 860 rounds and did not reveal any cracks. According to the Product Assurance Engineering Division, the failure occurred at 19 rounds into a firing test involving high pressure rounds (see Table I).

A search through archive records revealed that this baseplate was purchased from Bergman Forge on Contract 83-C-0133 which was amended to include eight thicker prototype baseplate forgings modified from Dwg. 7309126. It is unknown whether they were brought to SPEC QQ-A-367H, "Federal Specification for Aluminum Alloy Forgings." According to Bergman Forge personnel, the baseplates were forged at 750°F using 9-inch diameter by 9-inch long round 2014 aluminum alloy extrusions. Certification record data appear in Tables II and III.

PROCEDURE

A metallurgical evaluation consisted of the following analyses:

1. Visual examination
2. Dye-penetrant inspection
3. Scanning electron microscopy/energy dispersive spectroscopy
4. Chemical composition
5. Metallographic examination

6. Mechanical property testing

    a. Tensile

    b. Charpy impact toughness

    c. Fracture toughness

    d. Hardness

RESULTS

Visual Examination/Macrofractography

A visual examination of the baseplate (Figures 1 through 4) and of the fracture surfaces was conducted to identify any material and/or forging defects as well as to characterize the type of failure, i.e., fatigue, ductile, brittle, etc. An examination was also conducted to determine the origin of failure, if possible. Three fracture surfaces were created during the failure; two on the spades (Figures 2 and 3), one-third of the way from the hub to the outer ring, and one between the fillets of two adjacent triangularly-shaped holes (Figures 2 and 4). These locations have been previously identified as the areas of highest stress (ref 1), and have been the locations of cracking initiation in previous baseplate failures (ref 2), as well as fatigue-tested baseplates (ref 3).

These fracture surfaces were exposed for further examination as shown in Figures 5 through 8. The appearance of chevron-type markings indicates that this fracture, through the spades (Figures 5 and 6), initiated at the bottom of the spade and proceeded in a fast, unstable manner to the hub area. Neither a material or forging defect, nor evidence of fatigue were found at the fracture origin. However, the bottom of the baseplate, and the spades in particular, had been severely damaged and indented (see Figure 3). The appearance and the size of shear lips on this fracture indicate a relatively ductile type of failure.

Examination of the fracture surface at the hole fillets revealed chevron-type markings again which indicated that the fracture had initiated on one side and proceeded in a fast unstable manner through the spade to the other fillet. Close examination of the fracture origin, as determined by the chevron-type markings, did not reveal a pre-existing material or forging defect. Also, under stereoscopic examination, there was no evidence of a pre-existing fatigue crack. The presence of shear lips on this fracture surface also suggests a relatively ductile failure. Finally, a dye-penetrant inspection of the entire baseplate did not reveal any other cracks.

Scanning Electron Microscopy/Energy Dispersive Spectroscopy

Scanning electron microscopy (SEM) was utilized for a micro-examination of the fracture origins for pre-existing defects and to characterize the fracture mode. All three fracture surfaces were examined. Again, there was no evidence of a material or processing defect. Further, there was no fractographic evidence of a corrosion-assisted cracking process or fatigue striations. Figure 9 is a fractograph that shows microvoid formation and void enlargement about angular particles. This is a characteristic of a ductile fracture mode under high load. Several particles in the fracture surface were analyzed using energy dispersive spectroscopy (EDS) and were found to contain aluminum, silicon, iron, and manganese (Figure 10). The particles were thus identified as $(FeMn)_3SiAl_{12}$, which is a particulate common to 2014-T6 aluminum alloy.

Chemical Composition

A spectrochemical analysis of the chemical composition was conducted in accordance with paragraph 4.4.1 of Specification QQ-A-367H. The chemical composition as reported by the vendor and as analyzed by Benet appears in Table II.

The two analyses agree and show that the baseplate met the current required chemical composition and is typical of 2014-T6, a copper-alloyed, age hardenable aluminum grade.

Metallographic Examination

A metallographic examination of the microstructure was conducted to verify that the baseplate had undergone proper melting, forging, and heat treatment practice. The examination was also used to help analyze the SEM and mechanical property data. Figures 11 through 13 show the microstructure in a longitudinal plane of polish, adjacent to an uncracked fillet at the triangular holes. Figure 11 is an as-polished surface, showing several constituents aligned in the direction of material flow from forging. There is no evidence of shrinkage or gas porosity. Figures 12 and 13 show the microstructure of the same sample etched with Keller's reagent in order to examine for grain contrast, grain boundary lines, eutectic melting, overaging, and for identification of the constituents. The figures show a fine dispersion of $CuAl_2$ particles throughout a fine-grained aluminum matrix (typical of T6 aging) which contained three other constituents common to 2014 and which were present as much larger particles.

EDS was utilized to identify the composition of the particles shown in Figure 11. Figures 14 through 18 illustrate the elements found in particles on the polished and etched surface of a metallographic specimen. This analysis of elements, coupled with the gray levels revealed by Keller's reagent in optical microscopy, identified the larger particle constituents as $CuAl_2$, $(FeMn)_3SiAl_{12}$, and $Cu_2Mg_8Si_6Al_5$.

There was no evidence of rosette-shaped dendritic patterns indicative of eutectic melting, a condition which renders an aluminum forging defective by localized, solid solution melting under excessively high temperature forging conditions. Figure 19 shows the microstructure in a transverse plane of polish at higher magnification. Fine $CuAl_2$ precipitates outline a fine-grained aluminum matrix. Also visible, again, are large $CuAl_2$ precipitates (white, bottom right), larger $(FeMn)_3SiAl_{12}$ particles (black, bottom and bottom left), and and smaller $Cu_2Mg_8Si_6Al_5$ particles (gray, bottom right). These constituents, their size and amount, are typical for this alloy and do not indicate a defective melting practice.

Mechanical Property Testing

Mechanical property testing was conducted to verify that the baseplate met the requirements of Specification QQ-A-367H and that low mechanical properties did not contribute to the failure. Hardness, tensile, Charpy impact toughness, and fracture toughness specimens were taken from the baseplate at the locations and orientations shown in Figure 20. The grain flow pattern, as revealed by metallography, was used to sample for tensile properties parallel and perpendicular to the grain flow as specified in paragraph 4.2.3.1 of QQ-A-367H. Tensile, Charpy impact, and fracture toughness tests were conducted according to ASTM Methods E-8, E-23, and E-399, respectively. The properties are summarized in Table III and are representative of the fine-grained microstructures revealed through metallography. In all cases, the properties exceeded specified properties. Fracture toughness in this baseplate, which is not specified, was typical of that in 2014-T6 aluminum (ref 4). In summary, the mechanical properties in this baseplate are indicative of 2014-T6 alloy that has been properly melted and processed.

CONCLUSIONS

Baseplate SN EXP6 met all specifications in QQ-A-367H "Federal Specification for Aluminum Alloy Forgings," cited on Dwg. 11579870, M3A1 baseplate forging. There was no evidence of a defective material condition arising from either melting, forging, or heat treatment. Furthermore, there was no evidence of any pre-existing cracks in the plate. Fractography indicates that the primary mode of failure was a ductile, fast fracture under high load, at the highest stressed locations, with no detectable stable crack growth (fatigue) preceding the final failure.

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1. O'Hara, G.P., "Stress Analysis of a Mortar Baseplate as the Basis for Fatigue Testing," Technical Report ARLCB-TR-80017, Benet Weapons Laboratory, Watervliet, NY, May 1980.

2. Senick, J.R., "Failure Analysis of 81-mm Mortar Baseplate," Memorandum for Record, Advanced Engineering Section, Benet Weapons Laboratory, Watervliet, NY, November 1983.

3. Racicot, R.L., "81-mm Mortar Baseplate Dynamic Test," Memorandum Communication, Applied Mathematics and Mechanics Section, Benet Weapons Laboratory, Watervliet, NY, April 1980.

4. Aerospace Structural Metals Handbook, Metals and Ceramics Information Center, Battelle Columbus Laboratories, Columbus, OH, 1987 Edition.

TABLE I. SUMMARY OF HIGH PRESSURE ROUNDS JUST PRIOR TO FAILURE

Date	Round #	Cumulative	Pressure Reading (Ksi) Gage Copper	Pressure Reading (Ksi) Piezo
3/18/88	1	1979	14.9	15.2
	2	1980	15.2	15.0
	3	1981	15.3	14.9
	4	1982	15.5	15.2
	5	1983	15.8	15.7
	6	1984	15.4	15.1
	7	1985	16.0	15.0
	8	1986	14.7	15.1
3/22/88	9	1987	15.6	15.0
	10	1988	14.1	14.0
	11	1989	15.4	15.4
	12	1990	15.0	15.3
	13	1991	16.0	15.6
	14	1992	14.8	14.7
	15	1993	15.0	15.3
	16	1994	15.2	15.6
	17	1995	15.2	15.0
	18	1996	14.7	15.0
	19	1997	15.4	15.9

TABLE II. CHEMICAL COMPOSITION OF 2014 ALUMINUM BASEPLATE

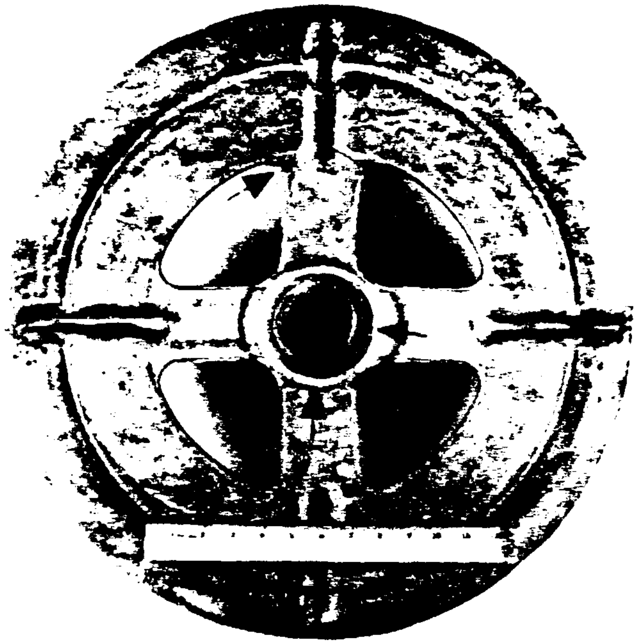
	Required*	Vendor	Benet
Copper	3.9-5.0	4.2	4.2
Silicon	0.50-1.2	0.75	0.71
Iron	0.7 max	0.45	0.38
Manganese	0.40-1.2	0.63	0.63
Magnesium	0.20-0.8	0.52	0.40
Zinc	0.25 max	0.10	0.14
Titanium	0.15 max	0.04	0.03
Chromium	0.10 max	0.02	0.01
Nickel	-	-	-
Aluminum	Bal		
Other**	0.15 max total	-	<0.4

*Table I, 2014, p. 3, QQ-A-367H, "Federal Specification for Aluminum Alloy Forgings"

**An analysis for the following typical impurities in 2014 was made: sodium, calcium, nickel, vanadium, sulfur, zirconium

TABLE III. MECHANICAL PROPERTIES

Specimen ID/ Orientation	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	% Elongation	70°F CVN (ft-lbs)	70°F K_{Ic} Ksi$\sqrt{in.}$	Hardness	
						R_b	BHN
Required (Long)	56 min	65 min	6% min	-	-	-	125 min
(Trans)	55 min	64 min	3% min				
T_1 (Long)	63.1	69.8	7.0			81	156
T_2 (Long)	63.9	69.5	7.2				
T_3 (Trans)	61.1	67.5	5.3				
T_4 (Trans)	61.1	66.3	5.8				
F_1 (Long)					-		
F_2 (Long)					26.5		
F_3 (Long)					23.2		
F_4 (Long)					24.2		
C_1 (Trans)				1.5			
C_2 (Trans)				1.5			
C_3 (Long)				2.5			
C_4 (Long)				2.5			
C_5 (Trans)				2.5			
C_6 (Trans)				2.5			
C_7 (Trans)				2.5			
C_8 (Trans)				3.5			
C_9 (Long)				2.5			
C_{10} (Long)				2.5			
C_{11} (Long)				3			
C_{12} (Long)				3			



Fiqure 1. Arrows pointinq out cracks and fracture surfaces on M3A1 baseplate.

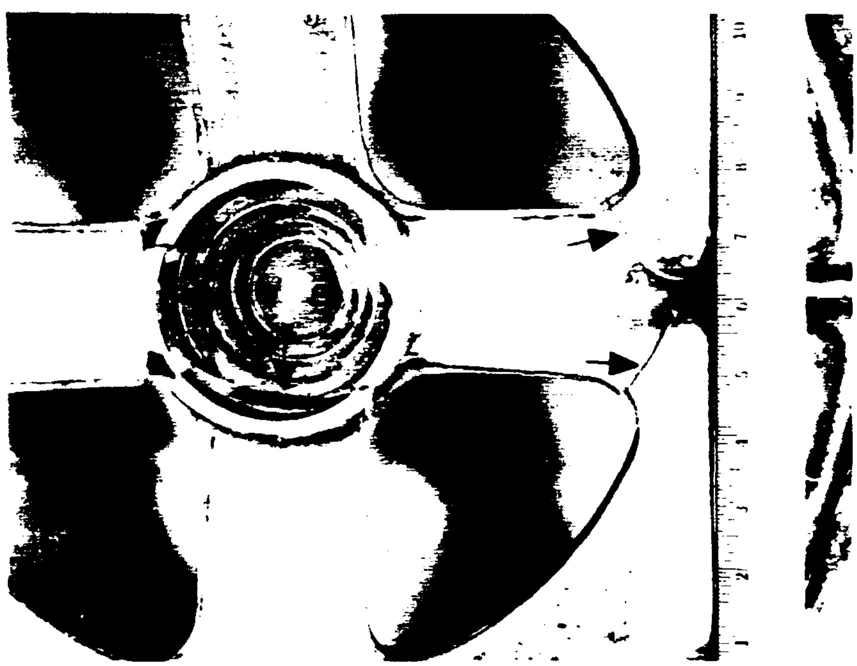
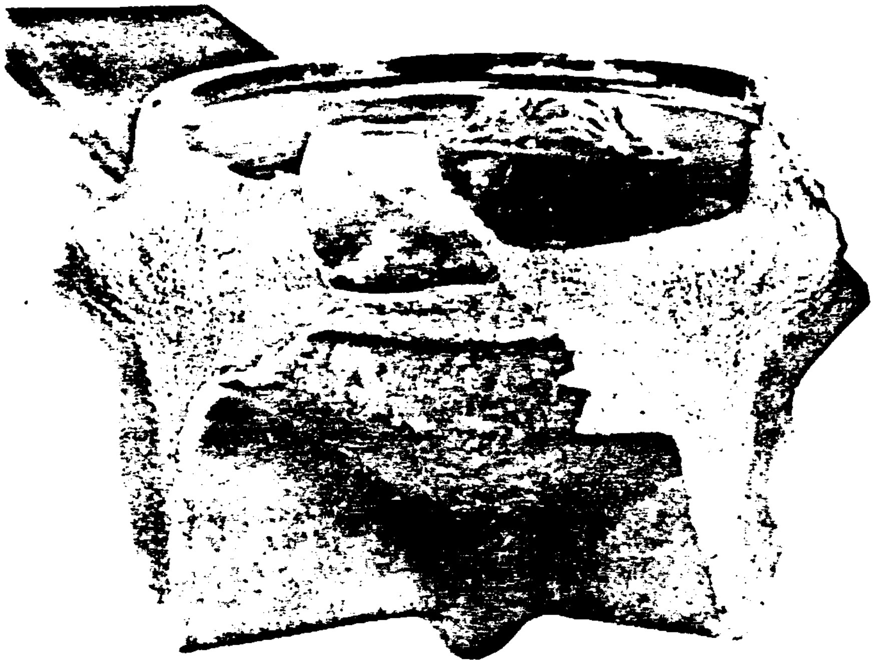


Figure 2. Closer view of same baseplate.

Figure 3. View of fracture through spade from underside of baseplate.

Figure 4. Fracture at fillet in triangularly-shaped hole in baseplate.



Fiaure 5. Surfaces of fracture througn the spades.

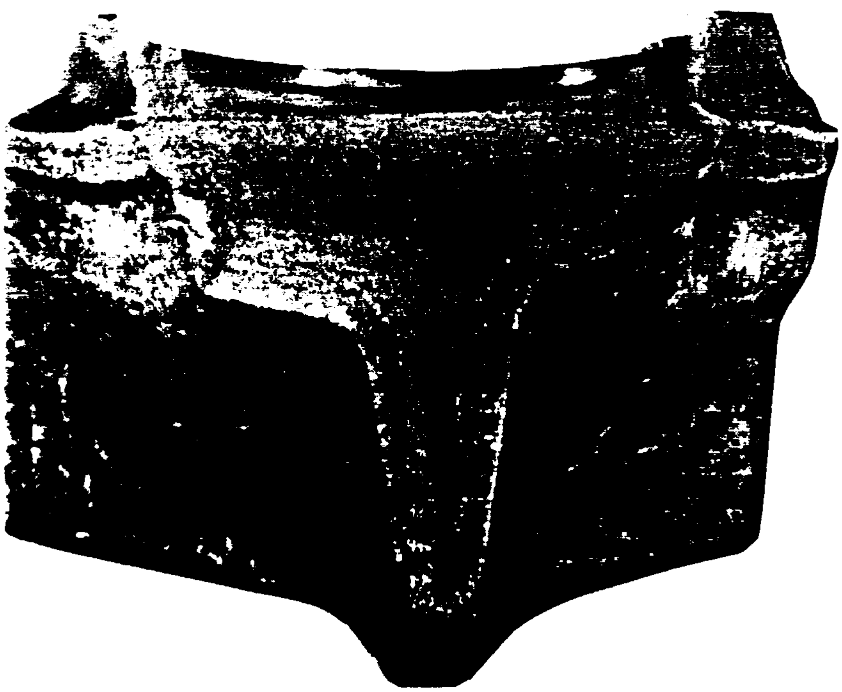


Figure 6. Flow lines of the fracture through the spade.

Figure 7. Fracture surface at the fillet.

Figure 8. Flow lines of the fracture at the fillet.

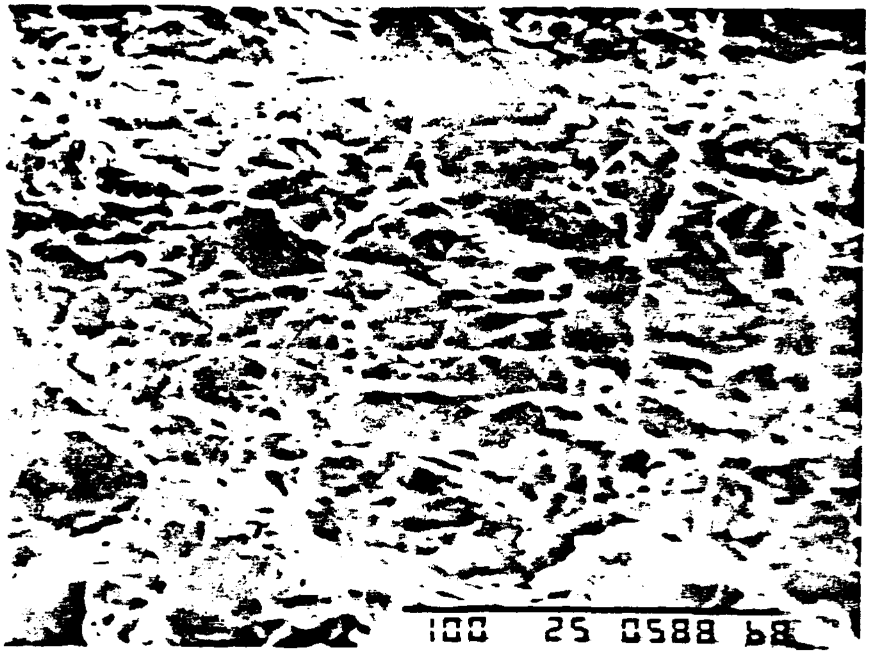


Figure 9. Microvoid formation and enlargement about angular particles. (500X)

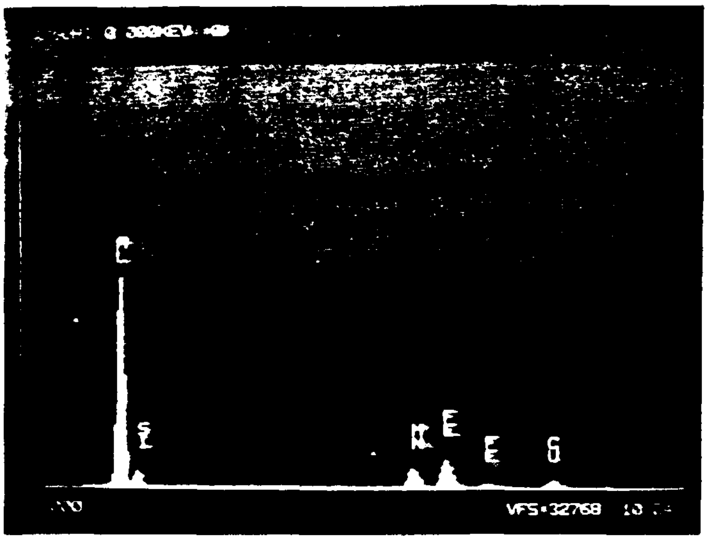


Figure 10. EDS analysis of angular particles shown in Figure 9.

Figure 11. Microstructure in longitudinal plane, as-polished. (100X)

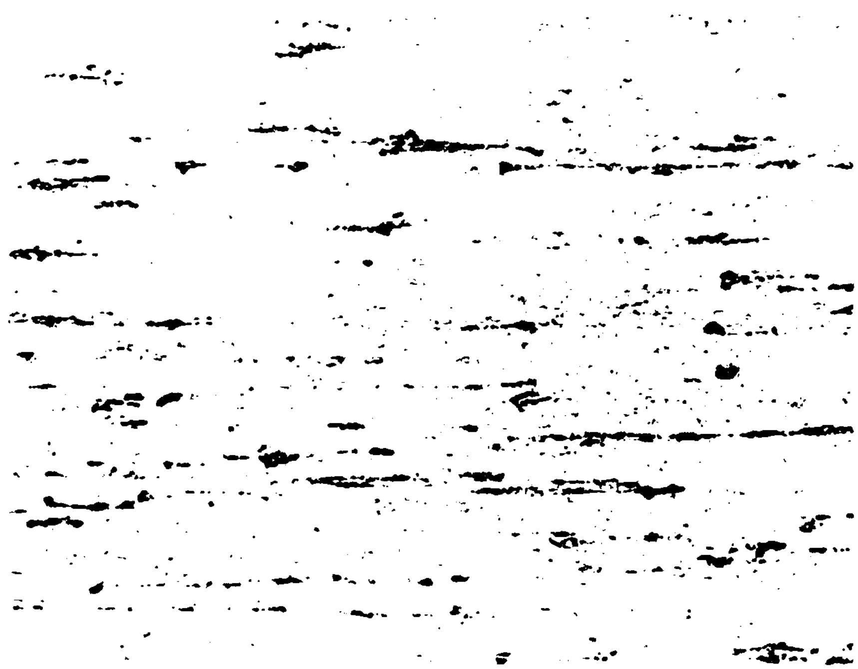


Figure 12. Microstructure in longitudinal plane, Keller's reagent. (100X)

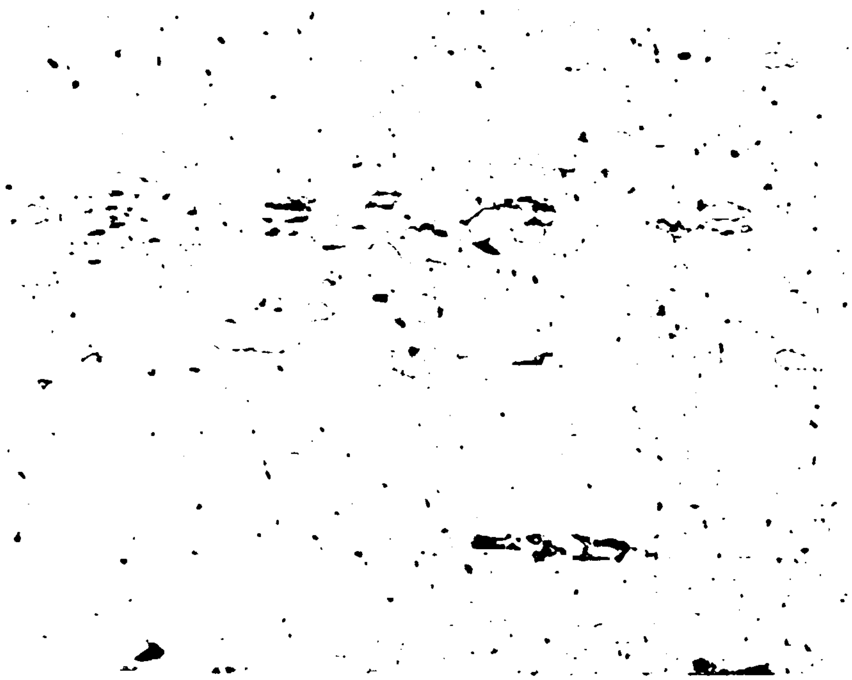


Figure 13. Microstructure in longitudinal plane, Keller's reagent. (500X)

Figure 14. SEM backscatter image of polished metallographic specimen. (1000X)

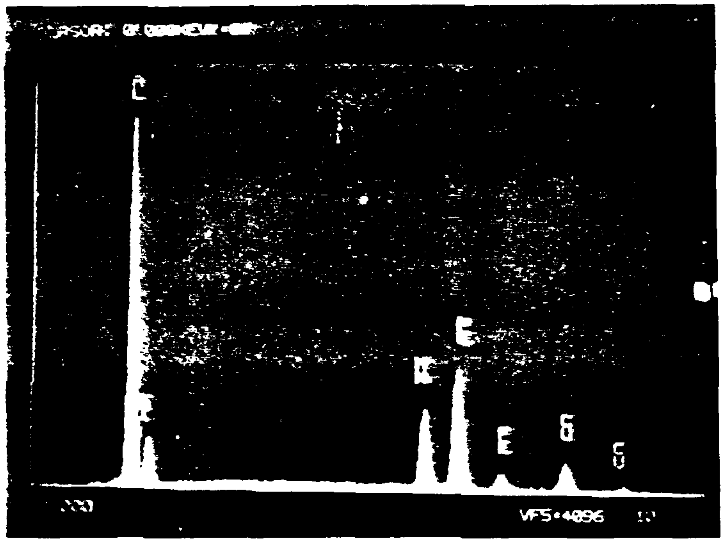


Figure 15. EDS analysis of microstructural constituents shown in Figure 14.

Figure 16. SEM backscatter image of polished metallographic specimen. (2500X)

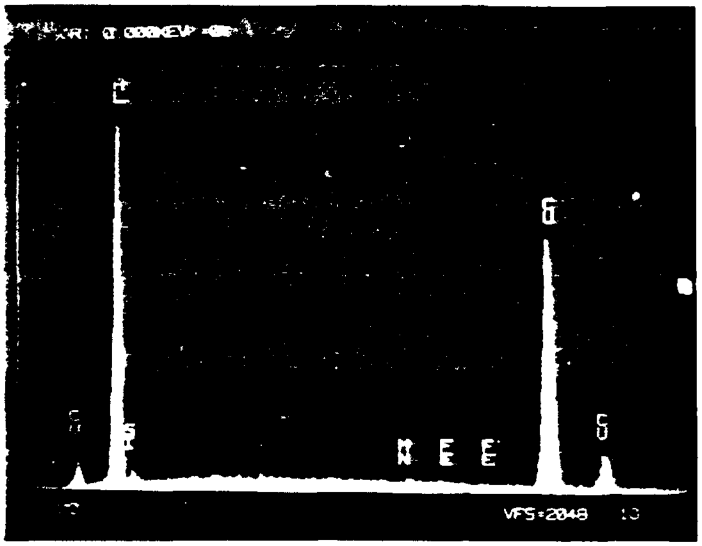


Figure 17. EDS analysis of white microstructural constituent shown in Figure 16.

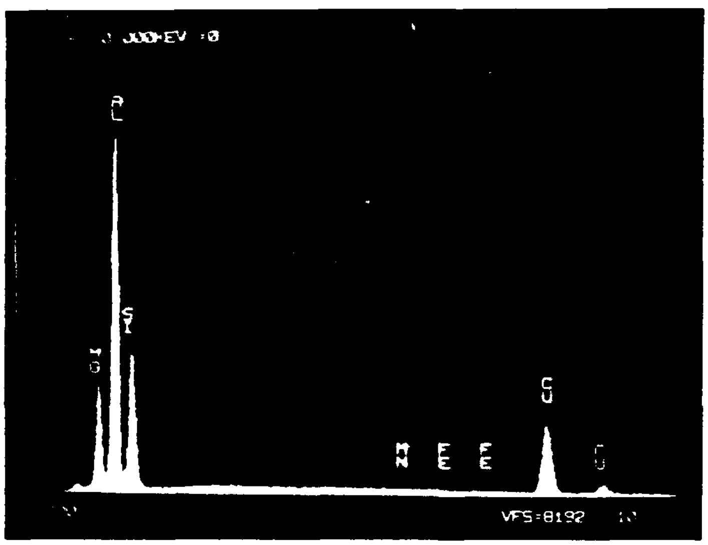
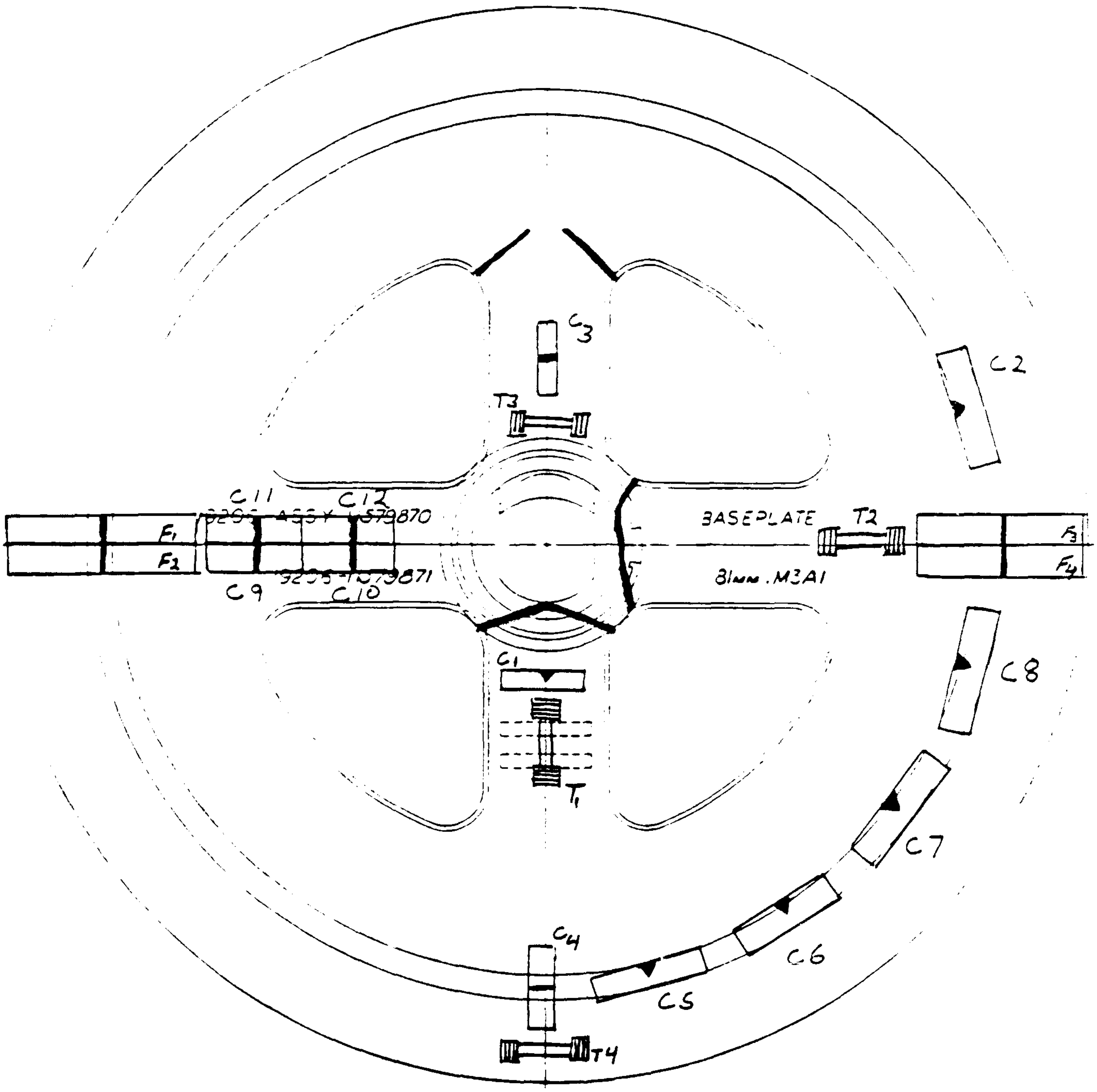


Figure 18. EDS analysis of small gray microstructural constituent shown in Figure 16.

Figure 19. Etched transverse microstructure, Keller's reagent. (1000X)



Key: T - Tensile
C - Charpy V-Notch
F - Fracture Toughness

Figure 20. Schematic of mechanical property specimen section.

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